DOCUMENT RESUME

ED 392 824 TM 024 479

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TITLE Processes Involved in Acquisition of Cognitive Skills.
PUB DATE Apr 95
NOTE 17p.; Paper presented at the Annual Meeting of the American Educational Research Association (San Francisco, CA, April 18-22, 1995).
PUB TYPE Reports - Research/Technical (143) -- Speeches/Conference Papers (150)

EDRS PRICE MF01/PC01 Plus Postage.
DESCRIPTORS *Cognitive Processes; *College Students; *Computer Assisted Instruction; *Encoding (Psychology); Foreign Countries; Higher Education; Simulation; Skill Development; *Teaching Methods; *Thinking Skills
IDENTIFIERS Knowledge Acquisition; *Procedural Knowledge

ABSTRACT

Processes involved in the acquisition of cognitive skills were studied through an investigation of the efficacy of initially encoding knowledge of a cognitive skill in either declarative or procedural form. Subjects were 80 university students. The cognitive skill, learning the steps to program a simulated video cassette recorder (VCR), was taught and tested through computer simulation. One group was given the task using declarative cues (stating each step in the sequence) and response demands, and another group was given procedural cues (touching each button in sequence) and response demands. Two other groups were given a combination of cue and response modes. The pattern of significant results suggested that the cognitive skill of programming a simulated VCR was developed most efficiently when subjects were prompted to respond to instruction using the procedures they would eventually be asked to use when performing the task. This supports the argument of D. E. Broadbent that cognitive skills are encoded in procedural form. (Contains 5 tables and 19 references.) (SLD)

Processes Involved in Acquisition of Cognitive Skills

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Running Head: **COGNITIVE SKILLS**

Paper presented at annual meeting of American Educational Research Association, San Francisco, April 17-22, 1995

Processes Involved in Acquisition of Cognitive Skills

Procedural knowledge is knowledge of **how** to perform activities. It consists of either motor or cognitive skills. Anderson (1982) suggested that procedural knowledge is stored as a system of productions. His influential analysis of the acquisition of cognitive procedures was based on Fitts' (1964) model of skill acquisition. This model suggested three stages in the development of skilled performance. The first stage, identified as the **cognitive stage** involved initial encoding of the skill and frequently encompassed verbal mediation. The **second stage**, the associative stage involved development of a more skilled performance. During this stage errors were removed and verbal mediation eliminated. During the final stage, the **autonomous stage**, proficiency in the skill was attained.

Anderson (1982) suggested that there are three analogous stages in the development of a cognitive skill. The first stage he referred to as the **declarative stage**, where information related to the skill is initially encoded as a set of facts about the skill. Thus, knowledge of the skill is first encoded in declarative form. The second stage he called **knowledge compilation**. During this stage practice of the skill results in transformation of the knowledge to procedural form, so that it can be applied directly without the need for interpretative processes. The final stage Anderson labelled the **procedural stage**. Knowledge is applied more appropriately and processes are accelerated as proficiency is developed. During this stage access to the declarative component of the skill is eliminated.

Thus, according to Anderson both motor and cognitive skills are acquired in three stages. The first involves encoding and has a declarative component, the second comprises transformation of the information to procedural form and the third develops proficiency in the skill. Anderson's analysis of the acquisition of cognitive skills has received broad general acceptance in the educational literature (Gagné, 1985).

However, research from a variety of areas suggests that the sequence described by Anderson is not the only or perhaps even the dominant means of acquiring skills. There is a growing body of research which suggests a possible alternative theoretical explanation for skill acquisition. In the area of motor skills a number of researchers have demonstrated distinctly different characteristics for memory for acts (procedural knowledge) and memory for verbal information (declarative knowledge) (Cohen, 1981; 1984; Engelkamp & Zimmer, 1985; Glass, Krejci & Goldman, 1989). Engelkamp and Zimmer (1985) proposed a multi-code theory to explain these findings. They suggested that distinct information is coded and stored in distinct systems (Zimmer and Engelkamp, 1985; 1989). These systems may work cooperatively in particular tasks. However, specific mental operations are possible and some information is accessible, if and only if, the stimuli are processed in a specific system. That is, performance of a motor task or the motor component of a complex task requires activation of the motor component of the memory trace.

Zimmer and Engelkamp (1989) define the memory trace as the residue of the information which is processed during encoding. This suggests a direct link between the encoding process and the storage structure and contrasts with Anderson's (1982) view which suggests that procedures are initially encoded through the declarative network. A number of consistent findings support the contention that in terms of motor skill, learning is enhanced if encoding involves enactment of the behaviour rather than verbalisation (Zimmer & Engelkamp 1989). In addition, Koriat, Ben-Zur and Nussbaum (1990) reported that this also holds for encoding information for future action.

While fewer studies have examined the acquisitions of cognitive skills, there is some evidence to suggest that cognitive procedures may not always be initially encoded in declarative form. For example, Sanderson (1989) examined the dissociation between skilled performance and verbalisable knowledge in a series of four experiments. In her second experiment she found a negative relationship between successful performance and verbal knowledge. However, she attributed this dissociation to the use of a graphical display which may have enhanced visual-spatial encoding and interfered with declarative encoding.

Similar "circumstantial" evidence is provided by Kamouri, Kamouri and Smith (1986). In comparing exploration-based and instruction-based training for acquisition of procedural device knowledge. It could be argued that their exploration-based training would be likely to facilitate procedural encoding while instruction-based training facilitated declarative encoding. They found that the representation in memory which resulted from exploration-based learning produced superior performance.

There is also some evidence from work on tacit knowledge or implicit learning to suggest that cognitive procedures may not always be encoded in declarative form. For example, using a task involving knowledge of an artificial grammar, Reber (1989) found significant dissociation between subjects ability to identify grammatically accurate constructions and their ability to verbalise about the rules they used to guide their decision making. Similarly, Broadbent and his colleagues (Berry & Broadbent, 1984; Broadbent, Fitzgerald & Broadbent, 1986; Hayes & Broadbent, 1988) showed a dissociation or implicit learning between verbalisable knowledge and ability to control a simulated sugar production task and Stanley, Mathews, Buss and Kotler-Cope (1989) found that subjects demonstrated a substantial degree of implicit learning resulting in dissociation between task performance and ability to verbalise about that performance. Additionally, Stanley et al. showed that not only is verbalisable knowledge limited, but that it is encoded late rather than early in the learning sequence. Based on his extensive series of studies Broadbent (1987) has argued that the acquisition of cognitive skills may occur in an order opposite to that posed by Anderson. This position directly contradicts Anderson's suggestion, that declarative knowledge precedes the acquisition of cognitive procedural knowledge.

The work on implicit learning and tacit knowledge has led to dispute and extensive controversy in the literature (Brody, 1989). There is sufficient evidence to question Anderson's widely accepted view that declarative knowledge precedes the acquisition of cognitive procedures. However, the literature suggesting that cognitive procedures may not necessarily have been coded declaratively is lacking in studies which experimentally manipulate encoding processes. Studies by

Cohen (1981), Engelkamp and Zimmer (1985) and Glass, Krejci and Goldman (1989) do this in relation to motor skills. However, research into cognitive skills has generally established a learning task and observed the acquisition process, testing for procedural proficiency and the extent of verbal knowledge. There remains the need for studies which deliberately manipulate the extent of verbal and procedural encoding of cognitive skills.

In addition to the theoretical implication the question of the role of declarative knowledge in the acquisition of cognitive skills is of considerable applied significance. Cognitive skills play an important role in school learning from learning to decode print and perform simple mathematical calculations to complex problem solving and sophisticated analysis and synthesis of ideas. Depending on the nature of the acquisition process, various instructional methods are likely to be more efficacious in facilitating the development of cognitive skills. Therefore this study aimed to test the efficacy of initially encoding knowledge of a cognitive skill in either declarative or procedural form.

Method

Subjects

Subjects were 80 university students who were recruited on a voluntary basis and paid for participation.

Instruments

Simulated Task. The cognitive skill was taught and tested using a computer simulated task. The task comprised learning the sequence of steps necessary to program a simulated video cassette recorder (VCR). The program had four components: setting the channel, the commencing and finishing times, and the date. A diagrammatic representation of a VCR appeared on the right-hand side of the computer screen. Non-semantic labels (eg A1, A2) were attached to the "buttons". Program information was displayed on the upper-left-hand-corner of the screen. It consisted of information on the channel; starting and finishing times of the program and the date. Declarative cues, when provided appeared on the lower-left-side of the screen in the form of verbal instructions (eg "press A1"). Procedural cues were provided by highlighting the appropriate "button" on the VCR.

Subjects were asked to learn the programming sequence by providing either a declarative response (ie stating each step in the sequence) or a procedural response (ie touching each "button" in the sequence). Declarative encoding was prompted by providing a verbal cue for each step in the programming sequence and requiring subjects to acquire knowledge of the task through verbal responding. Procedural encoding was prompted by highlighting the correct "buttons" to press on the video display and having subjects respond by pressing the buttons on a touch screen.

Procedure

Initially subjects completed a brief questionnaire on their familiarity with VCRs. They were then matched on questionnaire scores and randomly assigned to one of four treatment groups.

One group was given the task using both declarative cues and response demands, one group was given procedural cues and response demands. The other two groups were provided with each combination of cue and response modes.

Subjects were provided with five cued learning trials, followed by practice trials without cues. If an error was made on a practice trial, subjects were returned to compete another cued learning sequence. When a subject completed three error-free practice trials, testing was conducted. Testing comprised two further trials conducted in the same response mode as the practice trials. In other words subjects who had learnt the sequence by pressing the "buttons" were tested in the same way. Subjects who had learnt by saying the sequence were initially tested by verbalising the sequence.

Following completion of two tests in the learning mode two transfer tests were given. Initially subjects were given practice in the alternative mode of responding. This process was used particularly to allow students to become familiar with the touch screen. When students felt comfortable with the new mode of response two transfer tests were conducted.

Results

The study examined the effects of two independent variables: instructional cue, and response mode. Dependent measures included number of trials to criterion, mean latency of response on two tests (procedural responding and declarative responding) and mean number of errors on two tests.

Each dependant variable was analysed using an Analysis of Variance. The means and standard deviations for each dependent measure are given in Tables 1-5 along with the corresponding Analysis of Variance tables. Main effects were obtained favoring the procedural response mode on the trials to criterion measure (p = .049), the number of errors on the procedural test (p = .035) and the latency of response on the procedural test (p = .0004). Two interaction effects were obtained on the latency of response for both test modes. A post hoc analysis using Scheffe's procedure showed that the group that received declarative cues and responded verbally performed more poorly than the two groups responding procedurally on latency of response on the procedural test (p = .03). There was also an interaction on latency of response on the declarative test (p = .008) but Scheffe's procedure did not detect the location of the difference.

Insert Tables 1-5 about here

Discussion

Where significant results were obtained they consistently favoured the groups which learnt the sequence of steps by responding procedurally. This pattern occurred across a variety of measures. The trials to criterion measure indicates that subjects who learnt using procedural responding found the task easier to master than students who responded by verbalising a response. The lack of an effect for type of cue indicates that the sequence was easier to learn when subjects responded to touching the simulated keys regardless of whether they were given written instructions or instructions based on highlighted keys.

Significant main effects favouring procedural response on the latency of response and number of errors on the procedural test indicate that the sequence was more accurately and thoroughly encoded by subjects who learnt the sequencing by touching the simulated keys. This would appear to support Broadbent's argument that cognitive skills are more efficiently encoded in procedural rather than declarative form. Interestingly, it appeared that the nature of the instructional cue did not have a significant impact on performance.

The lack of a significant main effect on the declarative test may be explained in part by the fact that this test mode constituted a transfer task for subjects who learnt using procedural response. It is reasonable to expect that subjects would perform more poorly on a transfer task than on a task involving the same mode as learning the task. Thus, it would be reasonable to expect the procedural encoding group to perform more poorly than the declarative encoding group on the declarative test. However, there was no difference between groups on the number of errors made on the declarative test. On the latency of response measure the group receiving declarative cues and who learnt responding declaratively performed more poorly than groups receiving either procedural cues or using procedural response. Thus, it appears that the group who received both declarative cues and used declarative responding performed poorly regardless of whether they were tested in the same mode in which they learnt or in a transfer mode. Although the nature of the instructional cue did not appear to have any direct effect on either proficiency in learning or storing the sequence, it did seem to act as a buffer for students' performance when they were tested on a transfer task.

Unfortunately, a number of problems with the study potentially compromise the conclusion that learning the skill of programming a simulated VCR is facilitated if subjects' initially encode the skill in procedural rather than in declarative form. For example, it was not possible to directly compare different groups' performance across procedural and declarative tests. The two tests had different methods of responding; <u>pressing</u> a sequence of buttons or <u>saying</u> the sequence. These two forms of response would be expected to have different latencies for execution. Thus, only performance of the four groups on the procedural test or on the declarative test were directly comparable.

For students initially responding in the procedural mode, the procedural test measured performance on the learning task and the declarative test represented a transfer task. The reverse is true for students learning the task using declarative response. Therefore, direct comparison of performance on learning versus transfer tasks for each group could not be gauged.

Second, and more seriously the impact of the facilitating effect of visual-spatial encoding could not be gauged. The subjects who had exposure to either the highlighted buttons or were able to respond by pressing buttons had access to information that could facilitate visual-spatial encoding. This information could have advantaged these groups independently of whether they used procedural or declarative encoding. There is some evidence to suggest that visual-spatial information did not have a dramatic impact on the results. The impact of visual-spatial encoding would have been detected by main effects for cue where highlighting buttons was more effective than verbal cues. Alternatively, interaction effects could be expected where the groups that had a combination of highlighted buttons with declarative response or verbal cues with procedural response were superior to groups who had no access to visual-spatial information. In no case were these effects obtained. No main effects for cue were observed. The interaction effects on the latency of procedural test did not show significant difference between the group which had declarative cue and response and the groups which had use of highlighted buttons. Rather groups which had procedural responding were significantly faster than the group which had declarative cue and response.

In summary, the pattern of significant results suggests that the cognitive skill of programming a simulated VCR is developed most efficiently if subjects are prompted to respond to instruction using the procedures they will eventually be asked to use when performing the task. This supports Broadbent's (1987) argument that cognitive skills are encoded in procedural form.

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Table 1

Means, standard Deviations and Significance Tests on Trials to Criterion Measure

Cue	Response				Total Cue	
	Procedural		Declarative			
	M	SD	M	SD	M	SD
Procedural	.90	1.68	2.70	3.05	1.8	2.59
Declarative	2.35	3.17	2.85	2.08	2.6	2.66
Total Response	1.62	2.61	2.78	2.58		

Source	DF	Mean-Square	F	p
Cue	1	12.80	1.93	0.17
Response	1	26.45	4.00	0.05
Cue-Response	1	8.45	1.28	0.26
Error	76	6.6297		

Table 2

Means, Standard Deviations and Significance Tests for Number of Errors on the Procedural Test

Cue	Response				Total Cue	
	Procedural		Declarative			
	M	SD	M	SD	M	SD
Procedural	.05	(.22)	.45	(.89)	.25	.67
Declarative	.35	(.75)	.80	(1.32)	.58	1.08
Total Response	.63	(1.13)	.20	.56)		

Source	DF	Mean-Square	F	P
Cue	1	2.11	2.69	0.10
Response	1	3.61	4.60	0.04
Cue-Response	1	0.01	0.02	0.90
Error	76	0.78		

Table 3

Means, Standard Deviations and Significance Tests for Latency of Response on the Procedural Test

Cue	Response				Total Cue	
	Procedural		Declarative			
	M	SD	M	SD	M	SD
Procedural	47.61	(13.57)	55.06	(22.39)	51.34	18.66
Declarative	45.50	(12.66)	74.99	(32.48)	59.75	28.28
Total Response	46.56	(13.00)	64.53			

Source	DF	Mean-Square	F	P
Cue	1	1413.80	2.97	0.09
Response	1	6460.39	13.60	0.00
Cue-Response	1	2214.99	4.66	0.03
Error	76	475.09		

Table 4

Means, Standard Deviations and Significance Tests for Number of Errors on the Declarative Test

Cue	Response				Total Cue	
	Procedural		Declarative			
	M	SD	M	SD	M	SD
Procedural	.15	(.37)	(.30)	(.66)	.23	(.53)
Declarative	.10	(.31)	.20	.41)	.15	(.36)
Total Response	.13	(.33)	.25	(.54)		

Source	DF	Mean-Square	F	P
Cue	1	0.11	0.54	0.46
Response	1	0.31	1.51	0.22
Cue-Response	1	0.01	0.06	0.80
Error	76	0.21		

Table 5

Means, Standard Deviations, and Significance Tests for Latency of Response on the Declarative Test

	Response					
Cue	Procedural		Declarative		Total Cue	
	M	SD	M	SD	M	SD
Procedural	51.02	(15.19)	43.33	(9.41)	47.17	(13.06)
Declarative	42.47	(10.53)	51.14	(17.12)	46.80	(14.70)
Total Response	46.74	(13.61)	47.23	(14.20)		

Source	DF	Mean-Square	F	P
Cue	1	2.76	0.02	0.90
Response	1	4.81	0.03	0.87
Cue-Response	1	1338.42	7.40	0.01
Error	76	180.79		